Appendix J
Selected Results of Thinning

Thinning of *Tectona grandis* plantations in Puerto Rico resulted in a much greater growth response than was possible through fertilizer application (Briscoe and Ybarra-Coronado 1972). The application of nitrogen (N), calcium (Ca), and magnesium (Mg) to 3- to 16-year-old plantations had no significant effect on height or diameter growth. Although minor increases in height growth were attributed to added phosphorus (P) and potassium (K), concurrent thinning increased growth much more than even the best fertilizer treatment.

Thinning intensity does not always produce a sharply defined response. Subsequent overall growth may be about the same over a wide range of residual stand densities. This is illustrated by a thinning in a 16-year-old plantation of *Araucaria angustifolia* in Brazil (Soares 1970). The basal area per hectare was reduced in four treatments from 35 m^2 to 29, 18, 11, and 7 m^2. During the next 3 years, the basal area growth was 6 m^2/ha for the unthinned plots, and 7, 6, 4, and 3 m^2/ha for the thinned plantations. The treatment that reduced basal area from 35 to 18 m^2/ha reduced the number of trees from 2,500 to 800 per hectare, yet did not reduce volume growth. In percentage, however, volume growth rose from 34 to 62 percent.

One explanation for this nearly uniform response regardless of the intensity of thinning is that diameter growth of the dominant trees is not much affected by the removal of subordinates, be they few or many. This suggests the desirability of complete utilization of these subordinates where pulpwood or pole markets exist.

Light thinnings may not stimulate tree growth unless done very early in the life of the plantation. A thinning of 20-year-old *Calophyllum calaba* on an adverse site in Puerto Rico reduced the basal area from 26 to 18 m^2/ha but produced no evident growth response 2 years later (Anon. 1952o). The crowns of the released trees were still essentially as narrow as when thinned. However, the crowns did fill out gradually over many years, possibly indicating slow recovery after having been constrained by long stagnation before thinning.

The effects of different thinning intensities and policies are apparent in a study of an 8-year-old teak *(Tectona grandis)* plantation in Nigeria (Nwoboshi 1971). The results are presented in terms of remaining tree quality (table J–1). Samples were taken from six plots of each treatment, for an aggregate of 0.24 ha per treatment.

The trend in basal-area growth of three *A. angustifolia* trees in Brazil is of interest (Buch 1971). From age 10 to 20 (before thinning), their average basal-area growth was 140 cm^2/yr. From age 20 to 30, still before thinning, it was 144 cm^2/yr. From age 30 to 40, with the thinning in the 33rd year, it rose to 473 cm^2/yr, more than triple the previous average.

A detailed study of thinning effects on *Pinus elliottii* in the southern United States clarifies a number of relations that appear to have broad applicability (Mann and Enghardt 1972). Different parts of the plantation were thinned to 16 m^2/ha of basal area at ages 10, 13, and 16; 13 and 16; and 16 only. Although overall volume growth was reduced by the thinnings, as shown in table J–2, the diameter growth of the large trees rose above that of the unthinned plots, as seen in table J–3. This indicates some benefits from removal of subordinate trees.

In Brazil, thinning has been shown to extend the rise in the mean annual increment (MAI) of *Eucalyptus* plantations (Heinsdijk 1972). In unthinned first plantings, the MAI culminates in about the 8th year. In thinned plantations, the MAI continues to rise to year 11 and, with complete utilization of small poles, may not culminate until year 14.

Thinning of *A. angustifolia* in Misiones, Argentina, strongly influenced overall yield and mean tree diameter (Cozzo 1958). Trees planted at 1 by 1 m were thinned at year 5 to 2 by 2 m or 4 by 4 m. By year 11, the most intensely thinned plots had about three times the mean d.b.h. of unthinned controls but only about a third the basal area and MAI (table J–4).

In another *A. angustifolia* plantation in Misiones, thinning at 10 years reduced basal area per hectare from 24 to 20 m^2, and thinning at 17 years reduced it from 34 to 12 m^2 (Cozzo 1970). Net growth of the thinned plantation from age 10 to 20 was 26.1 cubic meters per hectare per year compared to 35.7 m^3/ha/yr for the unthinned control. Thinning paid off well in tree size; however, at age 20 all the trees in the thinned plantation were 26 cm in d.b.h. or larger, whereas, in the unthinned plantation, only 19 percent were this large.

In Nigeria, variation in tree growth in teak plantations was found to be strongly related (about 70 percent) to tree size at the beginning of the measurement period rather than to competition, as indicated by summed

Table J-1.—Effects of various intensities of thinning on an 8-year-old teak (*Tectona grandis*) plantation in Nigeria

Treatment	No. of trees left per hectare	Percentage of trees by quality class[a]		
		1	2	3
Unthinned	921	46	39	15
One-third of rows removed	659	48	32	20
One-half of rows removed	479	38	40	22
Basal area reduced to 16 m^2/ha[b]	598	53	38	10
Eclectic (quintet)[c]	440	61	33	6
Eclectic (quartet)[d]	427	59	35	6

Source: Nwoboshi 1971.
[a]1 = straight, sound dominants and codominants;
2 = dominants or codominants likely to be removed in subsequent thinnings;
3 = inferior trees.
[b]Low and crown thinning to yield fuelwood.
[c]Best of five in progression in each row.
[d]Best of four in progression in each row.

basal areas of surrounding trees (Lowe 1966). Thinning significantly reduces this variation, increasing the uniformity of growth rates among the trees.

An early analysis of sample plots in 11- to 21-year-old teak plantations in Java showed that conventionally thinned teak can even outproduce unthinned plantations (Hellinga 1939). Unthinned plantations had up to 250 percent as many trees as thinned plantations. They also had up to 200 percent as much basal area and up to 180 percent as much volume. The mean d.b.h. ranged from 70 to 95 percent of that in the thinned plantations. But, surprisingly, the ultimate volume of standing timber plus thinnings was 5 to 33 percent greater in the thinned plantations than in the unthinned ones.

Tests with *P. caribaea* in South Africa, where sawtimber is the final product but there is also a market for pulpwood, showed the advantages of initial close spacing and a heavy pulpwood thinning (Anon. 1954e). Plantations initially spaced at 2.1 by 2.1 m, rather than at the more conventional 2.7 by 2.7 m, yielded 21 m^3/ha more wood from the first thinning. This, plus the increase in diameter resulting from the thinning, more than compensated (in terms of cellulose yield) for the slower growth of individual trees at the closer spacing before the first thinning.

At Nilambur, India, a systematic first thinning has been followed by selection of about 10 percent of the elites for a total of 80 crop trees per hectare on site I and 120 per hectare on site III (Kaushik 1960). These crop trees have been released progressively.

Table J-2.—Thinning effects on volume growth of *Pinus elliottii* in the Southern United States

Age at thinning	Increment in cubic meters per hectare		
	10–13 yr.	13–16 yr.	16–19 yr.
10, 13, 16	89	79	77
13, 16		72	79
16			68
Unthinned	100	100	100

Source: Mann and Enghardt 1972.

Table J-3.—Diameter growth of largest trees after thinning of *Pinus elliottii* in the Southern United States

Age at thinning	Increment in cubic meters per hectare		
	10–13 yr.	13–16 yr.	16–19 yr.
10, 13, 16	105	133	148
13, 16		133	156
16			119
Unthinned	100	100	100

Source: Mann and Enghardt 1972.

Table J–4.—Effects of thinning on an *Araucaria angustifolia* plantation in Misiones, Argentina, treated at age 4 and measured at age 11

Treatment at age 4	Mean d.b.h. (cm)	Basal area (m^2/ha)	Mean annual increment (m^3/ha/yr)
Unthinned, 1 by 1 m	9.8	44.4	24.2
Thinned to 2 by 2 m	12.5	26.9	14.6
Thinned to 4 by 4 m	18.0	14.5	7.9

Source: Cozzo 1958.

Teak *(Tectona grandis)* thinning in India is generally from below (Mathauda 1954c). The thinned teak trees are highly marketable, which favors thinning long before sawtimber is produced. In Trinidad, the thinned trees are ripped with gangsaws and treated with preservatives to make fencing (Ross 1958). Slabs are converted to broom handles.

Open-grown teak in Thailand has wider crowns than most other trees. In youth, the root system extends beyond the crown, but the crown overtakes root spread later (table J–5). The implication here is to thin as heavily as possible without causing epicormic branching (Ngampongsai 1973).

In Ivory Coast, a 4,000-ha teak plantation was thinned at 7, 12, and 20 years, yielding a total of 75 m^3/ha of small poles (Tariel 1966). For the final felling at 60 to 80 years, 150 trees per hectare remained and were expected to attain a diameter of 30 to 70 cm at that time.

Table J–5.—Tree dimensions of open-grown teak *(Tectona grandis)* in Thailand

Age (yr)	D.b.h. (cm)	Crown diameter (m)	Root system diameter (m)
5	9.0	4.2	4.6
10	14.2	7.7	5.4
15	16.9	8.5	5.6
20	26.1	10.0	5.7

Source: Ngampongsai 1973.

A thinning schedule recommended for teak in Nigeria (Horne 1966) for site quality I was based on crop height rather than age (table J–6).

A different regime has been used for thinning teak in eastern Nicaragua, where annual rainfall is 290 cm and initial spacing is 3.5 by 3.5 m (816 trees per hectare). Stands were thinned 50 percent at 9 years, leaving 408 trees per hectare (Weidema 1965b). A second thinning at age 19 left 245 trees per hectare. The two thinnings yielded 104 m^3/ha.

An early thinning regime for *Cupressus lusitanica* in east Africa, directed toward limiting knots to a 10-cm core, was as follows (Graham 1945):

Age (yr)	No. of trees left/ha.
7	990 to 1,110
9	860 to 990
11	740 to 860
14	620 to 740
17	490 to 620
20	370 to 490
25	250 to 350

By 1955, thinning was slightly heavier, leaving only 740 trees per hectare at age 9 and 620 at age 11 (Pudden 1955). With the first thinning at age 7, about 620 crop trees were selected per hectare, even though others were left for a total of 990 to 1,110 trees per hectare.

Thinning of *C. lusitanica* in Kenya has been based on dominant tree height (Wormald 1967). Comparable thinning schedules for *Pinus patula* and *P. radiata* in Kenya appear in table J–7.

Table J–6.—Teak (*Tectona grandis*) thinning schedule in Nigeria for site quality I based on crop height

Crop height (m)	Age (yr)	No. of trees to leave per hectare
8	3	1,490
12	6	750
18	10	270
23	15	190
27	20	120
32	30	90

Source: Horne 1966.

Table J-7.—Thinning schedules for three species in Kenya

Dominant height (m)	No. of trees to leave per hectare[a] *Cupressus lusitanica*	*Pinus patula*	*P. radiata*
11–12	840	690	840
15–17	490–560		
17–18			420
18–21	330		
21–23		520	
26	250		
27		350	
30–31			280
37			200

Source: Wormald 1967.
[a]Data shown only for times of thinning.

A review of pine plantations in Kenya led to revisions in thinning practice (Paterson 1967b) based on the conclusion that denser stands could be carried without serious detriment to crop growth. The *P. patula* crop was expected to average 42 cm in d.b.h. at age 30 and 44 cm at age 35. The corresponding figures for *P. radiata* would be 54 cm and 58 cm (table J–8). Such a regime produces a final crop averaging 48 cm in d.b.h. and about 21 cubic meters per hectare per year in volume.

For *Araucaria hunsteinii* in Papua New Guinea, trees are spaced initially at 7 by 7 m (476 per hectare), and at 10 years, stands are thinned to 250 per hectare (Godlee and White 1976). At 20 years, they are reduced to 200 trees per hectare and at 25 years, to 100 per hectare. That final stocking level (100 per hectare) is maintained until harvest at 40 years.

In Misiones Province, Argentina, *A. angustifolia* plantings have been spaced at 2 by 2 m (2,500 trees per hectare) (Fraser 1965). At age 6, half the trees were removed, leaving 1,250 per hectare. At age 10, density was further reduced to 800 trees per hectare. At age 15, 500 trees per hectare were left. At age 20, the final thinning left 250 trees per hectare for a harvest at age 25.

Tests of three broadleaf tree species in Africa suggest that no thinning is necessary for at least 10 years if initial spacing is 2.4 by 2.4 m (Lowe 1970). Unthinned *Nauclea diderrichii, Terminalia ivorensis,* and *Triplochiton schleroxylon* exceeded mean diameters of 20, 32, and

Table J-8.—Thinning schedules for *Pinus patula* and *P. radiata* in Kenya

Age (yr)	No. of trees to leave per hectare *P. patula*	*P. radiata*
7	990	990
12	740	400
20	300	200

Source: Paterson 1967.

22 cm, respectively, by age 10. Basal-area growth culminated at 7 to 8 years for *Terminalia ivorensis* and *Triplochiton schleroxylon* and at 10 to 12 years for *N. diderrichii.* Even after 15 years without thinning, the growth of the crop trees was still acceptable.

In contrast, the extremely fast-growing tree *Ochroma lagopus* needs heavy thinning. Trees of this species were planted in Nigeria at the rate of 2,200 trees per hectare, or an average spacing of about 2.1 by 2.1 m, and thinned at 18 months to 1,550 per hectare. From these residuals, 400 potential crop trees were selected (Anon. 1961f, White and Cameron 1965). A year later, another thinning reduced the stand to 760 trees per hectare. At 3.5 years (another year later), a final thinning reduced the stand to 100 trees per hectare, and the harvest came in the 5th year.

Thinning experience with *Aucoumea klainiana* in west Africa suggests two general practices: (1) space initially at 11 by 11 m within natural forests and avoid thinning, and (2) space more closely and thin gradually to obtain 90 good dominant trees per hectare (Catinot 1969a). The first of these, which is well adapted for underplanting, keeps basal area less than 10 m^2/ha until nearly the 20th year. The final crop would attain a mean d.b.h. of 65 cm and a basal area of about 40 m^2/ha. The second practice calls for thinning to 180 to 200 trees per hectare at ages 8 to 10 and to 110 to 120 trees per hectare at age 15, or both thinnings may be combined at age 10. A complication with this species is serious epicormic branching. Heavy thinning (50 to 75 percent of the trees) brings about catastrophic crown descent. Thinning should be done early to confine any subsequent branching and consequent knots to what will eventually be the central core of the trees.

Thinning of *Gmelina arborea* plantations at Monte Dourado, Brazil, for products larger than pulpwood was projected for 3, 5, and 7 years (Anon. 1979e).